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Waterborne disease: occurrence is on the upswing

Edwin C. Lippy

Three of the waterborne disease outbreaks in 1979 typified problems common to many water systems. Investigation of the outbreaks identified as causative factors deficiencies in water treatment practices and plant operation and a breakdown in surveillance activities designed to protect public health. Preliminary information indicates that a total of 45 outbreaks occurred during 1979, increasing the annual average of outbreaks to 36 for the four-year period from 1976 to 1979. This represents a 50 percent increase over the 1971–75 average of 24. The five-year averages have steadily increased from an annual average of ten during 1951–55. Before that period the trend was declining.

The disturbing trend toward more frequent occurrence of outbreaks of waterborne disease should serve as a warning to all who share in the responsibility for the delivery of a safe and potable water. The "multiple barrier" concept that relies on placing protective systems between the water consumer and actual as well as potential sources of contamination should be emphasized, with appropriate consideration for natural features (distance, dilution, geologic factors), man-made facilities (adequate waste treatment, water treatment, operational considerations), and conscientious surveillance by regulatory agencies (monitoring, inspection, certification). Investigation of three of the outbreaks that occurred in 1979 illustrates what can happen when these barriers are neglected. The outbreaks occurred in Bradford, Pa.; a state park near Lake Havasu City, Ariz., and a church camp near Brevard, N.C.

Bradford, Pa.

Bradford is located in northwestern Pennsylvania about 210 km (130 mi) northeast of Pittsburgh and some 97 km (60 mi) south of Buffalo, N.Y. It is situated in the midst of the Allegheny oil region and is an industrial center for producing and refining crude oil.

The water system serves a population of approximately 18 000. Three impoundments located within a few miles of the city serve as sources of supply. The impoundments and watersheds are wholly owned and protected by the city, and recreational use is prohibited. Chlorination is the only treatment provided; gas injection facilities are located immediately downstream from each impoundment. Transmission mains convey water from the impoundments to the distribution system, where the supplies converge. A number of service connections draw off each transmission main prior to their convergence.

An open finished water reservoir of 13-ML (3.5-mil gal) capacity provides storage and regulates pressure in the distribution system. Chlorination is not provided at this reservoir. Data for each raw water impoundment are given in Table 1.

The outbreak begins. A waterborne outbreak was suspected when fifteen residents reported within one week to the

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Bradford Hospital for treatment of diarrheal illness. When tested, ten of the fifteen were stool-positive for *Giardia* cysts. Newspaper reports implicated the water supply and advised residents to boil their water. The advice was based upon reporters' discussions with state and city health officials and the Center for Disease Control (CDC) in Atlanta, Ga. The suspicion that the illness was related to the water supply probably arose from recent water quality problems.

Heavy rain in the Bradford area in July and August contributed to turbidity problems and resulted in numerous citizens' complaints of discolored and muddy water. This was compounded by public notification of failure to comply with the coliform maximum contaminant level (MCL) in August and September. The city was not required to report violations of the turbidity MCL because it had been granted a waiver by the Environmental Protection Agency (EPA). Records indicated that the reservoir at Marilla Brook had turbidity values in excess of 10 NTU on numerous occasions.

The bacteriological record appeared acceptable until August when three of twenty samples collected were reported to be positive for coliform bacteria (Table 2). Closer inspection of the record, however, showed that extensive time had elapsed between sample collection and analysis, casting doubt on the validity of all the results prior to the use of local laboratories in September.

Determining the cause. The Meadville regional office of the Pennsylvania Department of Environmental Resources invited EPA to assist in the investigation of the water system to isolate *Giardia* cysts from the water, identify the source of contamination, and propose corrective measures. Also, a team of epidemiological investigators was dispatched by the Pennsylvania Department of Health and was soon joined by a team from the Center for Disease Control.

Within ten days after the investigation was begun, cysts were isolated from the water system. A beaver trapped from a large lodge in the Gilbert Run reservoir was sacrificed for necropsy and a sample from the colon showed an abundance of *Giardia* cysts. At this point in the investigation the number of confirmed cases of giardiasis at the Bradford Hospital had increased to 180.

Precautionary measures taken at the outset of the investigation included a recommendation that consumers boil water for one minute and that plant operators increase chlorination to a concentration of sufficient strength to destroy *Giardia* cysts. Chlorine contact times were calculated for each source based on the flow in each main and the distance from the point of chlorine injection to the first service connection. These times were confirmed by increasing chlorine feed and clocking the amount of time it took for the increase to appear at the first service connection. The computed and observed times were in reasonable agreement, and chlorine doses were adjusted according to the most current information available for destruction of Giardia Cysts.

TABLE 1
Characteristics of reservoir facilities in Bradford, Pa., 1979

Raw Water Impoundment	Drainage Area		Storage Capcity		Average Output		Construction Date
	km²	sq mi	ML	mil gal	ML/day	mgd	
Reservoir 2 (Gilbert Run)	533	206	765	202	5.3	1.4	1913
Reservoir 3 (Marilla Brook)			454	120	4.1	1.1	1900
Reservoir 5 (Hazelton Mill)			2574	680	14.4	3.8	1955

TABLE 2
Coliform sample results for Bradford, Pa., 1979

Month	Number of Samples	Number of Positive Samples	Number of Samples and Time Between Collection and Laboratory Analysis				
			Same Day	2 Days	3 Days	4 Days	5 Days
January	25	0			25		
February	20	0			20		
March	20	0			20		
April	25	0			25		
May	20	0			15	5	
June	20	0		4	5	11	
July	25	0		5		15	5
August	20	3				15	5
September*	26†	5	21		5		
October	24‡	2	24				
November	19	0	19				
December	20	0	20				

*Began using local laboratory
†Includes six check samples
‡Includes two check samples

The chlorine contact time at the Gilbert Run reservoir was most critical at about 20 min, which required a chlorine dosage that would give a residual of 2.5 mg/L at the first service connection. Contact time at the Marilla Brook reservoir was 30 min, requiring a residual of 2 mg/L. The Hazelton Mill reservoir provided a contact time of more than 90 min, which permitted the use of a more reasonable chlorine dose. Feeding the entire system from Hazelton Mill was considered as a possibility but was rejected because inadequate pressure would prohibit service to all customers. However, after beaver lodges were found in both the Gilbert Run and Marilla Brooks reservoirs, the output from these sources was reduced and the deficit sustained by Hazelton Mill. Common problems noted at all of the chlorination facilities included antiquated equipment (a single chlorine cylinder was connected to the chlorinator, causing lapses in feed when empty cylinders were replaced so that if a 15-min change time at each facility occurred on the same day 250 kL [66 000 gal] of nonchlorinated water would be delivered to the system); inadequate chlorinator capacity; and an incorrect procedure for determining chlorine dose to achieve a residual in the distribution system. Chlorine residuals had been determined by collecting samples from a utility tap located a short distance from the injection point and adjusting the feed rate to attain 1 mg/L. This resulted in no residual in the system.

The city provided new chlorine feed equipment, which included manifolded cylinders with automatic switchover devices to improve the reliability of chlorination. Chlorination was the only protective barrier that could be employed in this situation, so uninterrupted, continuous disinfection was very important. Even though consumers had been instructed to boil water, this could not be considered an effective barrier because it was not known how diligently the boil water order was being followed in the community.

The Pennsylvania Game Commission estimated that six to eight beavers inhabited the lodge in Gilbert Run reservoir. It was suggested that they be trapped and moved out of the watershed; however, the commisson was concerned that the beavers would not survive in new surroundings that late in the year. Holding the beavers in captivity for release in the spring was then considered. Suitable holding facilities were not available and other problems associated with this

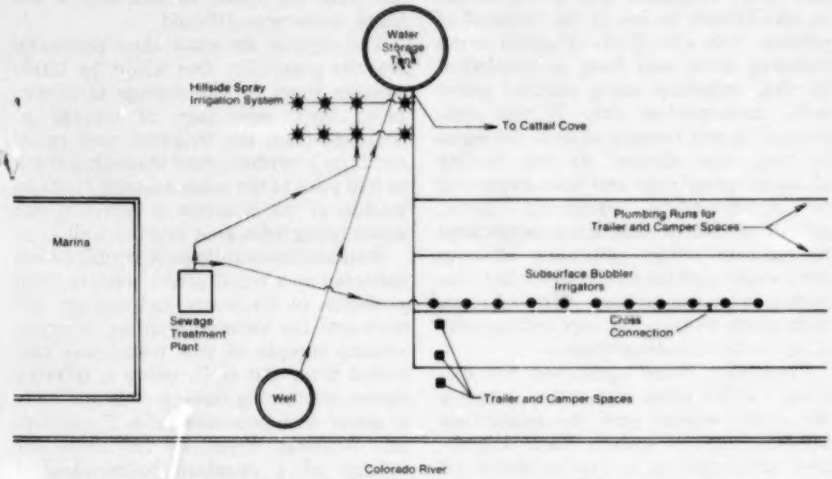

Figure 1. Water and sewage facilities for the Sand Point marina and campground

alternative made it unworkable. Eventually all the beaver in the Gilbert Run and Marilla Brook reservoirs and a few from the watershed of Hazelton Mill reservoir were trapped and sacrificed. Two beavers in Gilbert Run, one in Marilla Brook, and one in Hazelton Mill tested positive for *Giardia* cysts.

The number of giardiasis cases determined by positive stool examination at the Bradford Hospital eventually increased to 407. However, some local physicians began prescribing medication without the benefit of stool examination. Sales of drugs normally prescribed for giardiasis were recorded by city pharmacies as numbering 3487 during the six-week period beginning with the start of the investigation. The epidemiological study conducted by CDC and the state health department included a random household survey to identify occurrence and distribution of illness and collection of stool specimens to determine infectivity rate in residents of Bradford as well as a control community. The control community had little interaction with Bradford and used groundwater as a water supply source. The survey results showed that 5.4 percent of the Bradford residents had giardiasis-like illness (diarrhea for ≥ 10 days) with only 0.6 percent of the control community experiencing the same symptoms. Examination of stool specimens showed an infection rate of 16 percent for Bradford respondents (seventeen of 106 stools positive) and all 40 stools negative for the control community.[1] The stool infectivity rate applied to the Bradford population amounted to 2900 people affected.

The water quality problems that occurred before the outbreak generated numerous complaints, and public support was building for improvement of the water system. The additional inconvenience of boiling water combined with the noticeable odor created by increased chlorination fostered additional public pressure for action. The city directed a consulting engineering firm to begin a feasibility study for the provision of adequate treatment only eleven days after investigation of the outbreak began.

Rebuilding protective barriers. The Bradford water system is typical of many US systems faced with making improvements to comply with the National Interim Primary Drinking Water Regulations. In Pennsylvania alone there are 113 similar systems that rely on surface water as a source but do not have the facilities to reduce turbidity. From an energy conservation aspect, the Bradford system is very efficient, relying on raw water sources situated at sufficient elevation to maintain pressure throughout the distribution system without pumping. However, nearly two thirds of the system is unmetered, which is reflected in an average per capita demand of 1365 L/day (350 gpd) and in the size and cost of sewage collection and treatment facilities.

Breakdown occurred in all components of the protective systems in the multiple barrier concept. With information accumulating from waterborne outbreaks of giardiasis in California,[1] Washington,[2,3] Oregon,[1] and New Hampshire,[2,4,5] and other studies[6] implicating beaver as an intermediate host of the cyst that is transmitted to man, protective public health measures should be incorporated into the multiple barrier concept for certain water systems. Systems using surface water as a source of supply, with disinfection as the only means of treatment, should consider control of the beaver population in the watershed. Control measures may include periodic surveys to determine where lodges are being established, trapping during periods of the year when the beaver can be safely moved, and forestry practices that replace deciduous trees with coniferous species, thereby limiting the food supply along waterways and around reservoirs to discourage beaver habitation. These precautionary measures could be associated with natural and surveillance barriers, with both utility and regulatory agencies sharing the responsibility for implementation.

Other breakdowns that occurred were inadequate chlorination (man-made barrier) and ineffective microbiological monitoring (surveillance) which cast doubt on the validity of coliform results. The turbidity values prior to September were also questionable because the formazin standard was leaking. It is ironic that a waiver from compliance with the turbidity MCL was granted by EPA in this situation: such a waiver is predicated on qualifiers including demonstration that turbidity does not interfere with disinfection, prevent maintenance of an effective residual throughout the distribution system, or interfere with microbiological determinations.

State park—Lake Havasu City, Ariz.

Cattail Cove state park is located on the eastern bank of the Colorado River north of Parker Dam and south of Lake Havasu City. A recreational area located within the park is divided into two facilities, one operated by the state and an adjacent facility operated by concessionaires (Sand Point marina and campground). Sand Point, the larger of the two facilities, includes a store, comfort station, marina, and 170 spaces for campers and recreational vehicles.

The water system serving the recreational area is simple in design and operation. The source is a shallow well constructed in a diked area adjacent to the Colorado River, using bank storage or infiltrated river water. After chlorination, water is pumped to a hillside storage tank overlooking the two facilities. The Cattail Cove and Sand Point distri-

bution systems are fed by separate mains off a wye connection near the tank (Figure 1). Each facility has a sewage system consisting of a package plant with effluent disposal by irrigation.

Cause for concern. Disease control officials of the Arizona Department of Health Services requested assistance when they suspected a waterborne outbreak related either to swimming or water supply at the recreational area. Reports of illness began in June and continued through September. Most of the reports originated in California, which caused some problems in followup of cases. Of 74 cases investigated, four were stool positive for *Giardia* cysts. Information gathered by questionnaire suggested that drinking water at Sand Point was associated with illness.

Coliform sample results from the Sand Point water system showed two of two samples positive (TNTC and confluent growth) in June with followup check samples negative thirteen days later. (Two consecutive negative check samples were initiated on only one sampling point.) One of four samples collected in July was unsatisfactory (confluent growth) with no followup check sample, and one negative sample was collected in August. Samples from the state facility distribution system were all negative. Samples from the swimming areas showed coliform and fecal coliform results in excess of the single sample recommendation (200 fecal/1000 total) in August and September. After the Labor Day weekend beaches were posted with the warning that water quality did not meet standards and that swimming was therefore not recommended. While the preliminary epidemiological information implicated Sand Point drinking water, bacteriological data for the swimming areas also cast suspicion on water-related recreational activities. Suspicion increased when it was learned that the sewage plant serving Sand Point overflowed into the marina during a power failure in July. Overflow facilities had not been incorporated in the plant design.

Erratic evolution plagues system. The water and wastewater systems at Sand Point evolved over a period of six years under four different owners. An important feature unique to the Sand Point facility was the design of the sewage disposal system. The system was initially designed to dispose of the total sewage plant effluent through the use of subsurface bubbler irrigators. The design was based on 150 trailer or camper spaces utilizing 380 L/day/space (100 gpd/space) and 57 L/day/bubbler (15 gpd/bubbler), which required 1000 subsurface bubblers to irrigate an equal number of trees and shrubs. A surprising feature of the design was the use of the same type and color of pipe for the effluent irrigation system as for the potable water distribution system.

At some stage in the process of system development and changes in ownership, the installation of bubblers was halted and spray irrigation was added on an on-site hillside to aid in the disposal of effluent. Tree and shrub irrigation in the camping areas was then accomplished by drip irrigation using potable water with aboveground drip fittings submerged in pits formed around the bases of trees and shrubs. As the facility changed ownership and was expanded to accommodate additional trailer spaces, records or sketches were not kept to indicate where plumbing changes were made, and the extent of the bubbler system was not known. (The changes were made without the required approval by the health department.)

Conditions were optimized for creating a direct cross connection between the water system and the subsurface bubble-irrigation system. Each drip fitting submerged in a tree or shrub pit provided an entry point for contaminated water if subatmospheric pressure occurred in the water system.

To complicate the situation further, the location chosen for spray irrigation was on the side of a hill directly above the transmission main between the well and storage tank and the feed line to the campground. The feed lines to the campground were located in a gully at the base of the hill. Because the vegetation and soil on the hillside could not absorb all the effluent being applied, effluent ran off into the gully. To prevent drainage into the marina and beaches, small catchment areas were fashioned to retain the runoff in pools. These pools were located almost directly on top of the line carrying potable water. This presented another unusual situation.

When the well was developed, it was constructed in fill material placed to extend the bank into the river and form an infiltration gallery. Sufficient fill was excavated to set the well at a depth of 4.5 m (15 ft) and the material packed around the screen was to be selected and placed by specifications referenced on the engineering plan. It is assumed that this material was intended to be carefully selected, washed, and graded sand and gravel. However, local material was used in backfilling the gallery.

A raw water quality problem subsequently developed which is thought to be related to the use of material excavated from a local site that contains manganese. After chlorination, the water pumped from the well turned black in the transmission main to the storage tank, indicating the oxidation of manganese. The transmission main, rising about 45 m (150 ft) and running a length of approximately 300 m (1000 ft), served as an inclined settling tube that permitted an accumulation of black water which had to be bled off every three or four days and before weekends through a discharge port at the well and into the swimming area. This process discolored the river for about 30 min before the black water was diffused.

The unique situation thus presented was the possibility that while the transmission main to the storage tank was being bled, siphonage of sewage or drainage from the irrigated area could occur by a venturi effect through a crack or bad joint in the main, causing contamination of the beaches or affecting the water being infiltrated into the well.

Standard bacteriological samples were collected as a result of the concern with problems of the water and sewage systems and the swimming areas. A larger volume sample of raw water was collected from the well, using a filtering device containing three membrane pads in series with pore sizes of 5, 2, and 0.45 μm. Nineteen litres, or 190 times the volume of a standard bacteriological sample, were filtered through the pads for analysis of coliform and fecal coliform bacteria. (The pads were halved at the laboratory and processed separately for the analysis.) The large-volume sampling technique was used to detect low-level and, possibly, intermittent contamination.

Sample results showed no coliforms in the large-volume sample of raw water and no occurrence of contamination during bleed-off of the transmission main from the well to the storage tank. (The latter finding was also confirmed by a dye test.) Positive coliform and fecal coliform results were obtained on samples from the Sand Point distribution system in an area that served campers who had reported illnesses.

Discussion of the results with the departments of health services and state parks led to the agreement to close Sand Point marina and campground. By placing dye in the effluent pumping well of the sewage treatment plant, the northern regional office of the Department of Health Services in Flagstaff proved that a cross connection existed between the water system and the subsurface bubbler irrigation system. After dye was observed coming from the camp faucets, excavation located the cross connection. Extensive corrections were required to improve the water and sewage systems. Improvements also were required in surveillance activities, including prompt followup on positive coliform samples, timely reporting of results, and a review of the state regulations permitting installation of wastewater irrigation systems. Particular emphasis was placed on the necessity of color coding or use of dissimilar materials for water and wastewater piping.

Determination of the occurrence and

distribution of illness associated with this outbreak was difficult and time-consuming. Epidemiologists from the Department of Health Services were hampered in their investigative efforts by a number of factors, including (1) difficulty in locating visitors because of incomplete or erroneous identification entered on the camp register; (2) communication across state boundaries; (3) contact of visitors who might have been exposed five or six months before and would not remember; (4) selection of an appropriate sample population; (5) defining an incubation period where exposure to multiple pathogens could have occurred; (6) complications related to the possibility that the agent of hepatitis might have been involved; and (7) limited investigative resources.

Investigators eventually chose to interview a sample of the population that visited one of the two facilities on Labor Day weekend. A case was defined as a person who experienced a diarrheal illness during or within a three-week period after the visit. Results based on a telephone survey of 44 of 179 groups visiting Sand Point marina and campground and 14 of 42 groups who registered at the state facility showed that 57 (35.2 percent) of 162 campers from Sand Point were ill compared to only 6 (8.0 percent) of the 75 state park campers. The attack rate was significantly higher for Sand Point campers who consumed campsite water than for those who did not, and the incidence of illness was greatest in the vicinity of the cross connection. Approximately 6800 persons camped at Sand Point from June 1 through September. If water contamination occurred in this period, it is estimated that as many as 1900 persons may have become ill in this outbreak.[7]

Hazards lurk in noncommunity systems. The water supply serving Sand Point marina and campground is classified as a noncommunity system under the National Interim Primary Drinking Water Regulations. Current estimates place the total number of noncommunity systems at 250 000. Generally, this type of system has not received the same degree of attention from regulatory agencies as have the community water systems. The 59 000 community water systems have been given priority consideration in implementation of the Safe Drinking Water Act, which is not reassuring since they also suffer from lack of effective surveillance, as exemplified by the situation in Bradford, Pa. If such problems as those found at Sand Point marina and campground are common, regulatory surveillance will require substantial changes to control a potentially serious public health situation.

There was clearly a breakdown in regulatory surveillance for this system. Design criteria for reuse systems were not adequate, making review of plans and specifications ineffective. Procedures for inspections during construction and for changes after the system was in operation also were inadequate, permitting hazardous conditions to develop. Microbiological monitoring was not effective in followup procedures for positive samples.

The problems discussed that pertain to investigation of the outbreak do not fully describe the hazards observed in this situation. More than 100 potential cross connections existed with the drip irrigation system; drains for surface water could be mistaken for sewage hookups, allowing contamination of bathing areas; spray from the effluent irrigation system could drift over the camping area; valves on the water system were installed by bringing plumbing runs to the soil surface without using vaults or boxes; and potable water lines at the sewage dump station (for spaces without sewage hookups) were not properly protected.

Perhaps a more important concern is that noncommunity systems get the least regulatory attention and need the most. These water systems are frequently operated and maintained by untrained people and are beset with design, construction, and operational problems.

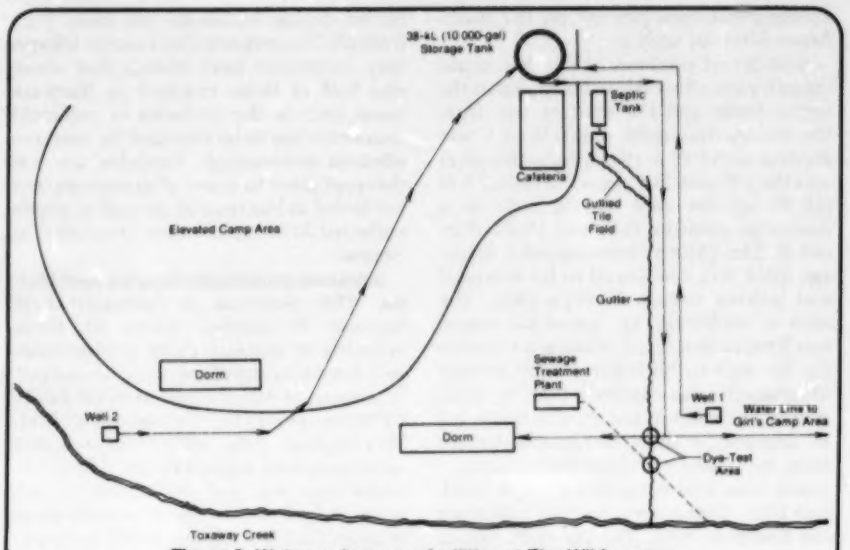

Figure 2. Water and sewage facilities at The Wilds camp

Church camp—Brevard, N.C.

A church camp named "The Wilds" is located in Pisgah National Forest in southwestern North Carolina. Religious groups use the camp for retreats held throughout the week during the summer months and over weekends during other seasons. Camp facilities include dormitories, assembly hall, cafeteria, and extensive recreational facilities.

The water system consists of two wells that supply untreated water to a storage tank from which it is pumped to the distribution system. The major water-using facilities discharge wastewater to a package sewage treatment plant. Septic tanks serve the few buildings inaccessible to the collection system (Figure 2).

Large number of illnesses closes camp. An epidemiologist with the North Carolina Department of Human Resources visited the camp the first weekend in November, after receiving reports of illness. It was determined that illnesses had been occuring in groups visiting the camp since August. A survey was conducted during the investigator's visit, with questionnaire results showing that 146 of 186 visitors were affected with vomiting and diarrhea within 24 hours of arrival. Stool and acute serum specimens were collected and arrangements made for collection of convalescent serum after a four-week interval. The camp was closed while the investigation evaluated food preparation and handling, general hygienic practices, and water supply and waste disposal facilities.

EPA participated in the investigation and evaluated water supply and waste disposal facilities. A large-volume water sample (1900 L [500 gal]) was collected for viral assay and 19-L (5-gal) samples for coliform and fecal coliform analyses were collected for each well using the filtering technique described in connection with the Arizona investigation. (Two standard bacteriological samples collected by the county sanitarian from the cafeteria kitchen the last two weekends in October were positive for coliforms.) Collection of 19-L (5-gal) bacteriological samples from each well on membrane filters showed coliform and fecal coliform contamination of well 1 but no

coliform colonies present on the membrane filter for well 2.

Sources of contamination that could conceivably affect the wells included the septic tanks and the effluent line from the sewage treatment plant. Well 1 was located about 15 m (50 ft) from the plant and the effluent line passed within 7.5 m (25 ft) of the well on its path to a discharge point in Toxaway Creek (Figure 2). The effluent line crossed a drainage ditch and was found to be damaged and leaking sewage in September. The area is underlain by limestone which can become fractured, making it possible for the well to be infiltrated by sewage effluent. (It was reported that an earth tremor occurred in the area in late July.) In addition, a short distance upstream from the location of the gutter crossing, a septic tank had been damaged. A truck had been driven over the site, rupturing the fiberglass tank. The tile field, which was located at the base of a steep slope, was eroded from surface drainage, and deep gullies had formed that drained into the gutter. It was therefore possible for sewage to enter the gutter from the ruptured septic tank or the gullied tile field. This, coupled with a water line crossing the drainage ditch and passing within immediate proximity of the well, was another possibility for contamination. Sewage flowing down the gutter could follow the path of the water line in the excavated and back-filled trench.

Both possibilities were tested by damming the gutter downstream from the water line and effluent line crossings and dosing the pool with fluorescein dye. The well was sampled unsuccessfully for fluorescein for three weeks. While fluorescein was apparently not charged into the well, it is conceivable that solution channels in the limestone strata became clogged and were sealed, preventing entry of the dye. Possibly other factors intervened. One septic tank that could have remotely influenced well 2 was also dye-tested with negative results.

The camp was permitted to reopen pending improvements which included installation of chlorination equipment on both wells, flushing and disinfection of the well system, and repairs to sewage disposal facilities. Well 1 was kept out of service during the opening weekend and no illness was noted among visitors.

Epidemiological survey data, reinforced by laboratory tests of medical specimens, determined that the agent responsible for this outbreak was a "Norwalk" type virus. Serological studies conducted by the Center for Disease Control showed that thirteen of fourteen symptomatic cases were seropositive for antibody titers against the Norwalk agent. Immune electron microscopy studies of stools from 35 ill volunteers failed to defect virus.[8] Detection of Norwalk agent in stool specimens collected during outbreaks has been very difficult. Volunteer studies under laboratory conditions have shown that about one half of those exposed to Norwalk agent excrete the particles in sufficient concentration to be detected by immune electron microscopy. Particles are not detected prior to onset of symptoms and are found in less than 20 percent of stools collected 72 hours or longer after onset of illness.[9]

Untreated groundwater supplies spell trouble. This outbreak is discussed here because it typifies many of those occuring in systems using groundwater as a source of supply without treatment. A review of the causes of waterborne outbreaks shows that for the period from 1971 through 1978, 107 of 224 reported outbreaks were caused by use of groundwater that was not chlorinated or not adequately treated. The outbreaks were responsible for a total of 17 391 illnesses. An etiologic agent was identified in fewer than half of the outbreaks, the remainder being characterized as acute gastrointestinal illnesses that were presumably caused by bacterial pathogens or enteric virus for which isolation and identification techniques were not available. It is not unusual for laboratories to culture specimens for only two bacterial pathogens, *Salmonella* and *Shigella*, and if they are not present, the causative agent is never determined.

There has been an improvement in the capability of some laboratories to detect other bacterial and viral pathogens that can be cultured. However, nonculturable viruses, which can be detected in stool specimens only by electron microscopy or through the use of stool material from infected individuals reacted with acute and convalescent serum to produce specific rises in antibody titer, have become increasingly associated with waterborne outbreaks in groundwater systems. It is typical of these outbreaks that investigators detect sources of sewage contamination in close proximity to wells but usually cannot demonstrate either through dye-testing or by sampling for microbiological indicators that contamination occurred. Viruses identified with these outbreaks are extremely small in size (in the range of 30–70 nm), which probably enables them to penetrate water-bearing aquifers whereas coliform organisms are trapped or die. Many factors interfere with dye-testing in groundwater situations, and the inability to demonstrate a positive test is not proof that the "likely event" did not occur.

Overall summary

A study of three waterborne disease outbreaks that occurred in 1979 shows that problems contributing to the occurrence of outbreaks can be identified and related to a breakdown of protective systems in the multiple barrier concept. Designers, utility personnel, and regulatory agencies share a responsibility for maintaining the integrity of the protective systems necessary to ensure the delivery of a safe and potable water.

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